Second beam orbit study to calibrate the SyncLite scale

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1 Introduction

The SyncLite system [1] measures the center positions of the proton and pbar beams and the sigmas of the 2-dimensional profiles. The scale for these measurements have to be calibrated. The synchrotron light is viewed by a CID camera with 640×480 pixels, so the calibration is given as mm/pixel.

The original Synclite scale from Run 1 was from optical imaging. The scale determined from the optical magnification together with the known camera/video pixel size was recalculated and checked against the original Run 1 scale [2]. This recalculation confirmed the original Run 1 scale for both the Synclite proton and pbar systems. However an earlier scale calibration of the pbar system using closed-orbit 3-bumps to move the beam position at the Synclite pbar radiation point a known (calculated) distance gave a pbar scale that was different from the original/optical scale by a factor of 1.8 [3].

This beam scale calibration has been repeated as a check. The scale calibration was again done by producing a bump in the beam position of a known (calculated) amount and comparing to that seen in the SL2 system. The mm/pixel scales for the horizontal and vertical should be the same, this should provide a good check of the calculated bump orbits. Also a check of the tilt of the SL2 system relative to the Tevatron can be made with this calibration data. For the earlier beam calibration done on 1st May 2002, only the pbar system was studied [3]. The study presented here was done for both protons and pbars.

2 Description of Data Taken

The calibration bump study data presented in this memo for protons and pbars were taken on 13th August 2002. Closed orbit 3-bumps were made to produce shifts in position of the beam at the SL2 radiation points for protons (`begin SLPDIPOL` in the lattice file) and for pbars (`end SLPBHDIP` in the lattice file.) The horizontal bumps were produced using HDB49, HDC11 and HDC13 while the vertical bumps were produced using VDB49, VDC11 and VDC14.

The data for all bunches were data logged every minute so the analysis was performed on these data from all bunches (from about 7:45am to about 8:50am.) For each vertical and then horizontal bump setting data were collected over several minutes before bumping the beam to a new location. For each minute the averages over the 36 bunches of the fit positions, sigmas and intensities are calculated. Although the different bunches have different intensities and

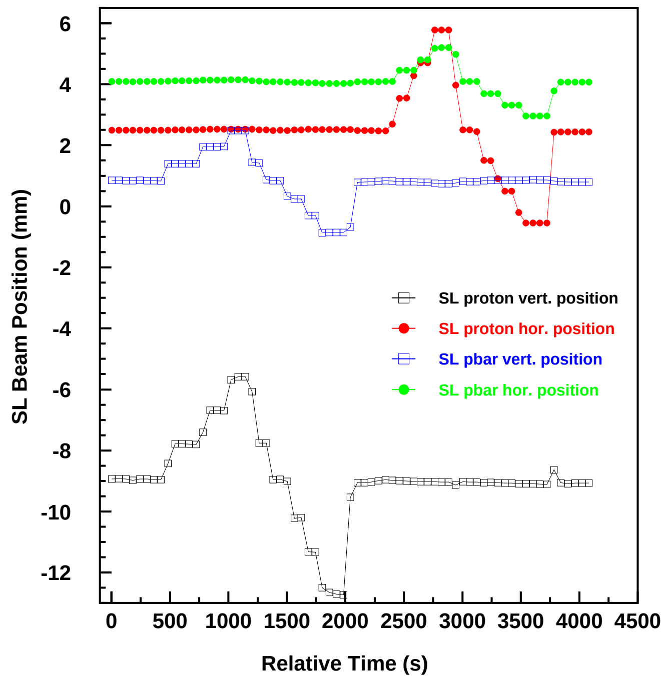


Figure 1: Vertical and horizontal positions of the proton and pbar beams as reported by Synclite for the duration of the beam bump study.

slightly different sigmas, all bunches have about the same position so using the average over all bunches is sufficiently accurate for this study [1]. The average over bunches gives one data point for that minute and is assigned an error equal to $\sigma_{r.m.s.}/\sqrt{36}$. (Note that the true error can be larger since each bunch has slightly different positions.) The data for the beam positions, sigmas and intensities are given in Figures 1 and 2 respectively.

The data shown is for 7 different beam positions from 6 vertical and 6 horizontal bump positions on either side of the nominal beam position. Note that the sigmas and intensities extracted from the proton vertical projections show strange behaviour at the relative time of about 1800 sec. into the study. This was because for that vertical position of the proton beam the image was clipped as it was overlapping the edge of the active area of the CID camera sensor. This data point is therefore not used for the proton fit.

The size of the bumps used at HDC11 and VDC11 as given by the currents were nominally ± 1, ± 2 and ± 3 mm. These displacements have to be translated into sizes of bumps at the radiation point of the proton and pbar synchrotron light. This was obtained using orbit calculations by A. Xiao [4]. The results of her study are reproduced in Figure 3.

[1] A more accurate measure of the beam position movement would be to take the differences in position for each bunch and then average these differences.

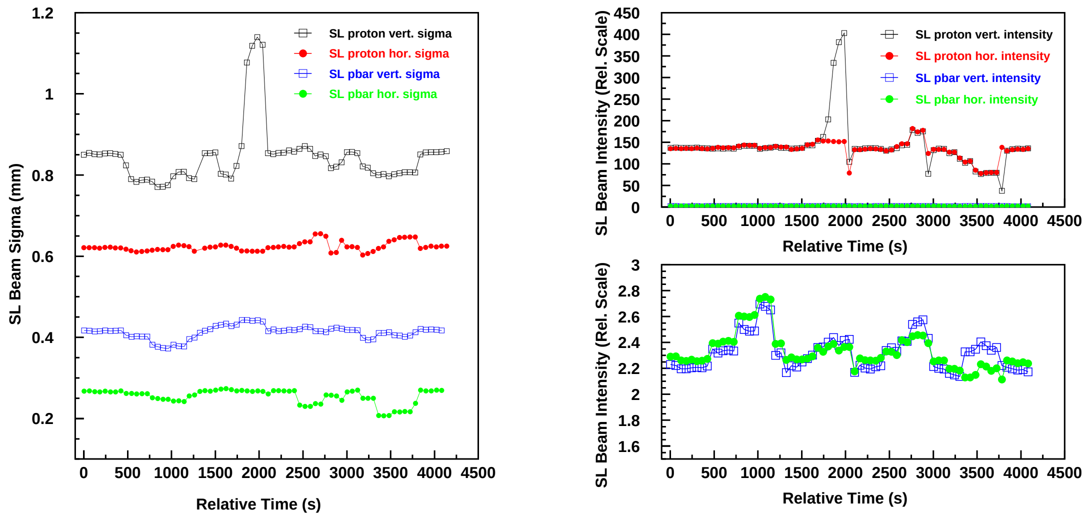


Figure 2: Vertical and horizontal sigmas and extracted intensities of the proton and pbar beams as reported by Synclite for the duration of the beam bump study.

3 Results From Fitting the Data

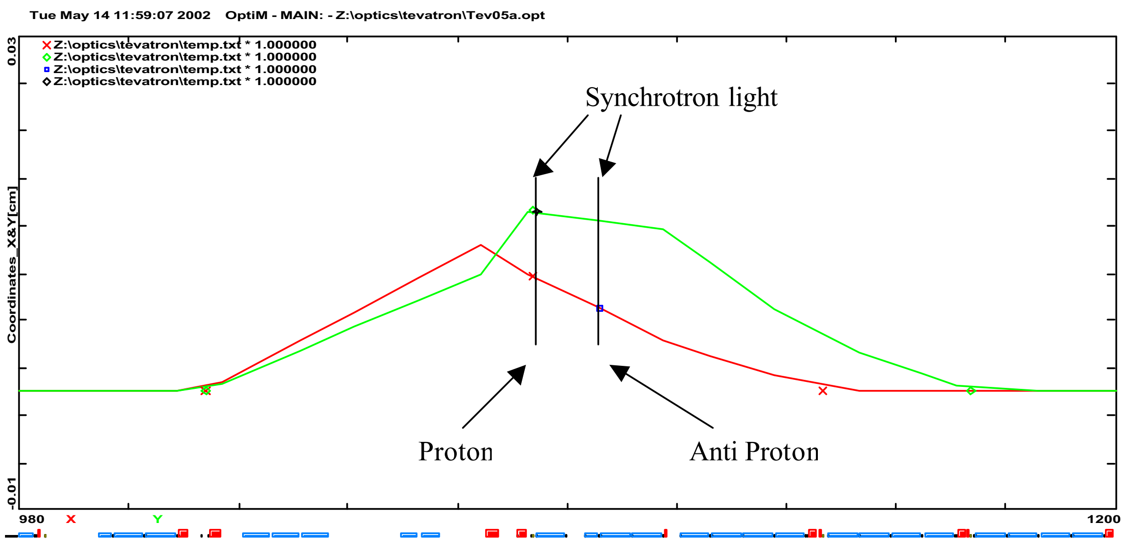
The data were fitted to obtain relative calibration scales. The results of the vertical bump and horizontal bump fits for protons are shown in Figure 4. The results for pbars are shown in Figure 5. The results are also summarized in Table 1. Note that for these studies the original Run 1 scale was used in the Synclite system, *i.e.* 0.058 mm/pixel for the proton system and 0.083 mm/pixel for the pbar system.

The vertical and horizontal SL scales are in fairly good agreement. (Note that the errors quoted for the slopes only include statistical uncertainties in the data taken. One expects the true error to be dominated by the uncertainties in the expected bump displacements.) Taking a simple average, this study shows that the proton SL scale should be smaller by a factor of 1.11 ± 0.05 and the pbar SL2 scale should be larger by a factor of $\frac{1}{0.557} = 1.80 \pm 0.12$. The vertical and horizontal scales should agree so I take the difference between the vertical and horizonal scales as an estimate the error in the scale factors.

The smallness of the horizontal beam position shifts for vertical beam displacements and vice versa show that there is no significant tilt in the proton and pbar SL2 systems. From the fits to the data and taking into account the scale factors for the two systems given above we can calculate the size of any tilt in the two systems.

For the proton system, the data is consistent with no tilt since any tilt would give slopes of opposite sign in the two bump data plots shown in Figures 6. From the data one can put a limit of $|\theta_p| < 0.32°$.

The pbar vertical and horizontal bump data indicates that the SL2 system is slightly



N	L	NAME	X[cm]	Y[cm]	Px[mrad]	Py[mrad]	Bx_ef[kG]	By_ef[kG]
1386	95679.44	kVDB47	0 0	0 0	0	0		
1431	98531.79	kHDB48	0 0	0 0	0	0		
1479	101734.59	kVDB49	6.12163e-27	9.99328e-11	1.22433e-19	0.00199866	6.12574e-13	10000
1480	101734.59	kHDB49	9.99328e-11	2.99798e-10	0.00199866	0.00199866	10000	0
1527	108318.97	kHDC11	0.009737	0.0152271	-0.00206654	0.000735054	-9291	0
1528	108318.97	kVDC11	0.009737	0.0152271	-0.00206654	-0.000633026	-4.19307e-13	-6845
1532	108387.44	isPSYNC	0.0095955	0.0151837	-0.00206654	-0.000633026	0	0
1546	109639.66	isPBSYNC	0.00700233	0.0143984	-0.00207524	-0.0006197	0	0
1574	111130.88	kVDC12	0.0039869	0.0132083	-0.0013132	-0.0031146	0	0
1618	1 14143.32	kHDC13	5.30855e-07	0.00418526	-1.09435e-07	-0.00140247	7109	0
1661	117117.66	kVDC14	2.20676e-07	-3.27357e-07	-2.39993e-08	-8.01672e-07	4.6182e-13	7539
1704	120094.55	kHDC15	1.37253e-07	-2.90747e-06	-8.16151e-08	-1.7781e-06	0	0

Figure 3: Orbit calculations at SyncLite from A. Xiao [4]. Horizontal orbit displacements at SL (x_p and x_{pbar}) are related to that at HDC11 (x_{bump}) by: $x_p = 0.9855 \times x_{bump}$ and $x_{pbar} = 0.7191 \times x_{bump}$. Vertical orbit displacements at SL2 are related to those at VDC11 by: $y_p = 0.9971 \times y_{bump}$ and $y_{pbar} = 0.9456 \times y_{bump}$.

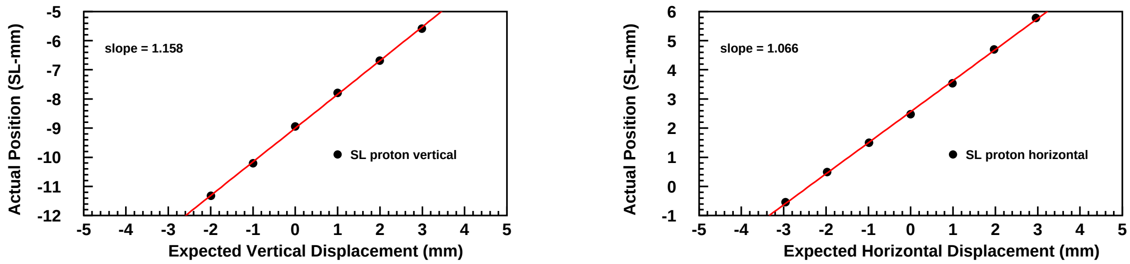


Figure 4: Vertical and horizontal positions of the proton beam as seen by SyncLite compared to expected vertical and horizontal displacements. The slopes of the fitted lines give the relative SL vertical and horizontal scale factors.

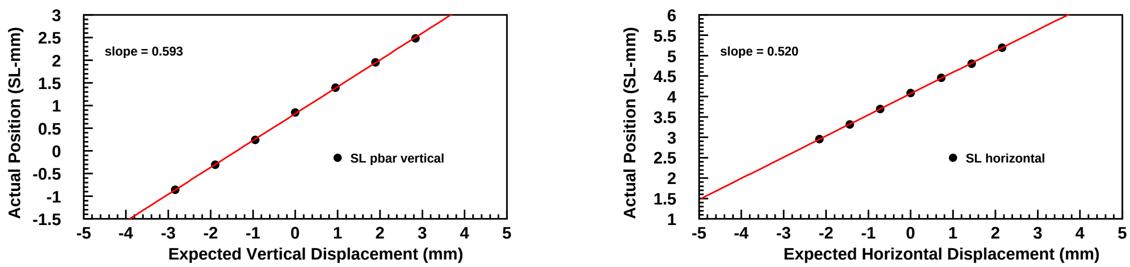


Figure 5: Vertical and horizontal positions of the $\bar{p}$ beam as seen by SyncLite compared to expected vertical and horizontal displacements. The slopes of the fitted lines give the relative SL vertical and horizontal scale factors.

rotated counter clockwise with respect to the Tevatron system by 2.4° and 2.8° respectively. This is illustrated in Figure 8 where we have taken the average tilt of $\theta_{\bar{p}} = 2.6°$. Again the two tilt angles should agree, using this would imply an error of about $\pm 0.2°$. However in the previous beam bump study a tilt angle of 1.6° was measured. Combining these two measurements I give the tilt angle of the SL2 system with respect to the Tevatron system as $(2.1 \pm 0.5)°$

4 Angular Effects due to Bumping the Beam

Note that although bumping the beam 1 mm can cause an horizontal angle change in the beam of 20 mrad, this change in angle and therefore in angle of radiation of light should not cause a change in the position of the image since the light is captured by a lens focusing at the camera. Light from each point in the object already radiates in a cone and the whole of this cone is focused to a point at the image. Hence no corrections are needed for any angle effects if the CID camera is correctly positioned at the focal point of the lens. This was checked when we checked the optical scale [2].

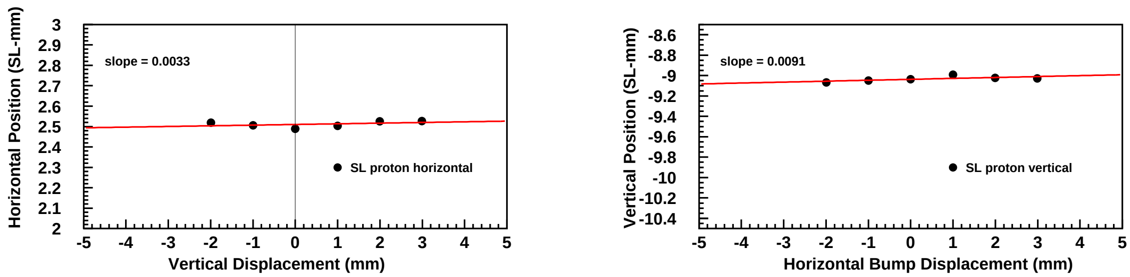


Figure 6: Horizontal and vertical positions of the proton beam as seen by SyncLite for vertical and horizontal beam displacements respectively. The slopes of the fitted lines give the tilts of the SL system with respect to the Tevatron system.

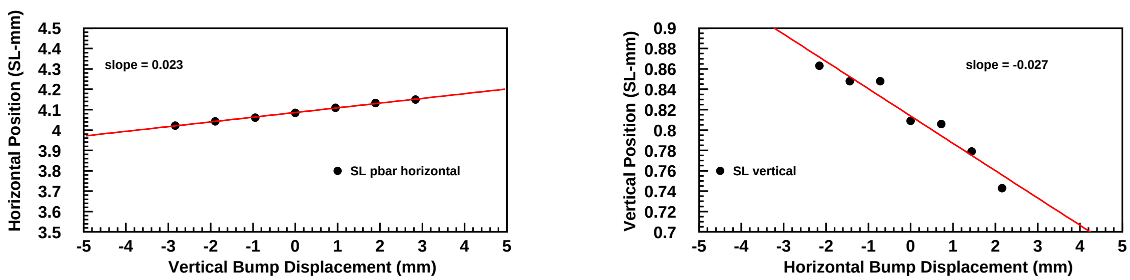


Figure 7: Horizontal and vertical positions of the $\bar{p}$ beam as seen by SyncLite for vertical and horizontal beam displacements. The slopes of the fitted lines give the tilts of the SL system with respect to the Tevatron system.

Table 1: Summary of results for bump data fits.

	Proton	
Quantity	**Slope in Vertical SL fit**	**Slope in Horizontal SL fit**
Vertical bump	1.158	0.0033
Horizontal bump	0.0091	1.066
	Pbar	
Quantity	**Slope in Vertical SL fit**	**Slope in Horizontal SL fit**
Vertical bump	0.593	0.023
Horizontal bump	-0.027	0.520

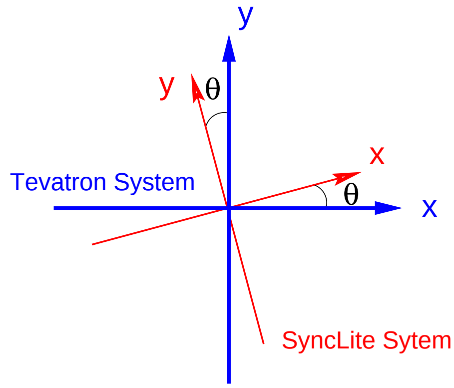


Figure 8: Schematic showing a possible small tilt of the SL2 system with respect to the Tevatron system of $\theta \approx 2.6°$. The positive y axis points up and the positive x axis points away from the center of the Tevatron orbit.

5 Conclusions

The pbar beam bump study shows that the SyncLite pbar scale should be increased by a factor of 1.80. The Run 1 scale is 0.083 mm/pixel, so the new scale factor should be 0.149 mm/pixel. This is in disagreement with the optical scale which agrees with the old Run 1 scale[2]. This disagreement is still not understood but the beam study scale is now used. This significantly increases the calculated pbar emittances compared to using the optical scale. The proton beam bump data shows that the proton mm/pixel scale of 0.058 mm/pixel is a factor of 1.11 ± 0.05 too large, (*i.e.* should be 0.052 mm/pixel.) However due to the sizable uncertainties the two scales agree within errors and so we are continuing to use the optical scale. There is no evidence of a significant tilt in the proton SyncLite system compared to the Tevatron system, but the pbar SyncLite system is rotated with respect to the Tevatron system counter-clockwise by a small angle of $(2.1 \pm 0.5)°$.

References

[1] `http://home.fnal.gov/~cheung/synclite/`.

[2] H.W.K. Cheung and S. Pordes, "Studies for the Synclite Scale", February 18, 2003, Synclite/2003/002, Beams-doc-466.

[3] H.W.K. Cheung, "Bumping the orbit to calibrate the SyncLite 2 scale", June 27, 2002. SyncLite/2002/001, Beams-doc-215.

[4] A. Xiao, "Orbit displacements at synchrotron light and correctors due to local 3-bumps", Beams-doc-238.